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SUMMARY OF FINAL REPORT

# Analysis and Application of Shielding and Protection Factor Research


Summary by

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SUMMARY OF FINAL REPORT

OCD Work Unit 1115C

Analysis and Application of Shielding and Protection Factor Research

by

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## Summary

### I. SCOPE AND OBJECTIVES

This constitutes the final report of the research completed under Office of Civil Defense Subtask 1115C, Analysis and Application of Shielding and PF Research, Contract No. OCD-PS-64-56. The objectives of this research were to: (1) determine if existing methods for computing protection factors agree with experimental data; and (2) recommend new investigations in areas where gaps exist in current shielding knowledge. This research supplements the findings of OCD Subtask 1115A (Reference 1).

The research subject areas which were analyzed included: modeling techniques, basement dose rates, simulated fallout, interior partitions, ceiling shine, ground roughness, azimuthal sectors, limited strips of contamination, and non-uniform source distributions. These analyses were used to determine the status of the present protection factor (PF) computational procedures including: Spencer's Monograph (Reference 2), AE Guide (Reference 3), Engineering Manual (Reference 4), Shelter Design and Analysis, Volumes 1 and 2 (References 5 and 6), NFSS Computer Program (Reference 7), Canadian and British AE Guides (References 8 and 9), Point Kernel Method (Reference 10), PM-100-1 Supplement 1 (Reference 11), the Praeger-Kavanagh-Waterbury Computer Program (Reference 12), and the RTI CDC-3600 Computer Program (Reference 13).

## II. APPROACH

The work for this project was divided into two categories: (1) evaluation of full-scale and model experimental data, and (2) status of theoretical predictions of experimental results. These analyses are included as Chapters 2 and 3, respectively.

A review of gamma-ray shielding literature was made, personal visits were made to organizations involved in shielding research of the type required for protection factor analyses, and discussions were held with the experimenters at these organizations. Also, well-known experts were consulted for comments and opinions on applicable research. The organizations visited included the following: Nuclear Defense Laboratory (NDL); Protective Structures Development Center (PSDC); National Bureau of Standards (NBS); Technical Operations Research (Tech Ops); Edgerton, Germeshausen, and Grier, Inc. (EG&G); the U. S. Naval Radiological Defense Laboratory (NRDL); and the U. S. Naval Civil Engineering Laboratory (NCEL).

## III. FINDINGS

### A. Introduction

The National Fallout Shelter Survey has shown that there is a shortage of adequate fallout shelters. If protection factor calculations are in error, adequate shelters may be rejected in the NFSS. Therefore, it is important to have the best possible estimate of the protection factors (PF). Many experimental and theoretical investigations of structure shielding against fallout have been performed. Methods for theoretical prediction of experimental results are continually being revised to update them and bring them more in line with experiments. The major findings of the research review and the status of the computational procedures are presented in the following paragraphs by subject area.

### B. Full-Scale Experiments

Several laboratories have performed full-scale experiments with calibrated sources and measured radiation intensities at different locations within structures. These experimental results were compared with Engineering Manual computations for certain cases. The major findings of the review of these experiments are:

1. In general, Engineering Manual theoretical reduction factors were within a factor of two of EG&G full-scale experiments on various structures (see Reference 1 for details). For a wood rambler house, the computed protection factor at the center of a bathroom shelter agreed within 4 percent with EG&G experimental values.

2. Early computational methods, such as Reference 9, predicted protection factors which were lower (conservative) by a factor of 1.5 or more when compared with Tech Ops experiments on various full-scale structures. Included were an Army barracks type of structure, an underground shelter, and residential type structures. For an open hole and residential basements, the theoretical predictions were conservative by a factor of 2 to 3.

3. Roof contributions measured by NDL for a full-scale concrete blockhouse agreed within 1 to 15 percent with Spencer's Monograph (Reference 2). Backscattered radiation was believed to have caused a discrepancy between experimental and theoretical ground contributions which varied with detector height. Experimental values were lower at 6 feet above the floor and

higher both at floor level and 1 foot below the floor.

4. NDL experimental and theoretical reduction factors (Spencer's Monograph) for ground contribution in a full-scale concrete blockhouse with wall weights of 48 to 139 psf agreed within 15 to 20 percent; the exponential attenuation of dose rate as a function of wall thickness was confirmed for detector heights of 0, 3, and 6 feet.

5. In unexposed and exposed basement experiments, with and without a first floor slab, NDL found that theoretical predictions based on Spencer's Monograph were usually non-conservative by as much as 30 percent.

6. For ground contribution through a single wall of a sand-wood blockhouse, DRCL found a dose rate midway between the center and sidewall to be 10 to 30 percent greater than at the center. Scattering was believed to be the source of this discrepancy, but effects of point sources rather than plane sources make this explanation questionable.

C. Model Experiments

The modeling approach to measurements of radiation attenuation in structures has been used by various laboratories. The major findings of the analysis of model experiments are:

1. In general, modeling is a useful and convenient method of estimating data on fallout protection afforded by full-scale buildings for first story and upper story locations. For both exposed and unexposed basements, uncertainties still exist which must be resolved before results can be considered completely valid. However, it is felt that the trends displayed by basement model data will be present in full-scale structures.

2. Experimental values of wall-scattered radiation, $G_s(\omega)$, were found to agree within 20 percent of Engineering Manual predictions by Tech Ops using a 1:12 scale steel model.

3. The basement dose rate increases by a factor of 2 for an infinite plane of contamination as the first floor slab becomes fully exposed, whereas the increase is by a factor of 4 for a 12-inch-wide plane (12-feet full-scale) adjacent to the Tech Ops 1:12 scale steel model building.

4. A correction factor to account for variation of basement dose rate with depth was derived from the Tech Ops model data in the course of the present research. The correction factor increases smoothly with depth.

5. The ratio of dose rate at the corner of a 1:12 scale steel model basement 3 inches below the first floor to that at the center is essentially unity for an infinite smooth field and increases to 1.3 for a limited field 24 inches wide (24-feet full-scale). This result seriously disagrees with the Engineering Manual (Reference 4), which will always predict a <u>decrease</u> in this ratio for ground contamination.

6. Monte Carlo and Moments Method shielding calculations were found to agree with Tech Ops experimental 1:12 scale steel model data, which show that two slabs are generally more effective than a single slab of equal mass thickness. The Engineering Manual procedure of using the product of barrier factors for the two-slab case is nonconservative by up to 30 percent when compared with experimental values.

7. Single slab buildup factors for plane-parallel radiation were found by NRDL to be always higher than for buildup factors in steel model compartmented structures. The largest discrepancy was 30 percent.

8. Failure to scale the density of ground and the density of air were estimated experimentally by DRCL to affect a 1:10 scale steel model shielding study by less than 10 percent for ground contribution.

9. Tech Ops, NRDL, and DRCL found that increasing the number of interior partitions makes model results increasingly nonconservative in predicting full-scale dose rates from ground contribution (i.e., dose rates predicted by the model are less than actual dose rates).

10. DRCL experiments indicated that an accuracy of $\pm$ 10 percent should be possible in scaling concrete walls with iron.

11. The Engineering Manual predictions agreed within 10 percent with Tech Ops 1:12 scale steel model data for a centrally located detector at the 3 foot first-story level, exposed to an infinite field of contamination. This supports the claim that the scaling procedure for simple structures with above-ground detectors is reasonably accurate.

12. Agreement between Tech Ops 1:12 scale steel model finite field data and the National Fallout Shelter Survey Computer Program (Reference 7) was not good (3 to 100 percent) for narrow planes, and was within 30 percent for wide planes (ratio of plane width to detector height greater than 10).

13. In the course of the research, it was noted that the dose rate per unit area of source distributed uniformly along a line parallel to the building walls varies inversely as the square of the geometric mean of the source-wall distance and the average source-detector distance. This enables determination of contribution from an outer plane of contamination by means of a simple equation if contribution from the inner plane is known.

14. The ratio of the dose rate of an upper story corner position to that at the center depends significantly both on the width of the plane of contamination and on the floor mass thickness. For width-of-plane to height-of-detector ratios less than or equal to 10, the ratio was found by Tech Ops in 1:12 scale steel models to be 1.4 for 20 psf full-scale floors and 2.5 for 80 psf full-scale floors. The corresponding factor for an infinite field and 50 psf full-scale floors was found to be 1.04.

15. Because of an interest in determining weathering effects on fallout, minimum theoretical computations were made using Tech Ops' model data. It was found, for example, that if a building (36 ft. wide x 48 ft. long) were surrounded solely by a limited plane of width $W_c$ = 24 feet, the relative increase in dose rate at a first story detector location would be 38 percent if all of the radioactivity on the roof fell on the ground next to the wall. If, however, the building had been surrounded by an infinite plane of contamination, the increase would have been only 8 percent. Therefore, redistribution of fallout does not cause a significant change in PF if there is an infinite plane of contamination.

D. Simulated Fallout

Because of impracticality of using real fallout, the pumped source method of simulating fallout has been developed. The major findings of the review of the pumped source method of fallout simulation are:

1. The pumped source method is conservative when compared with real fallout on the ground and roof of a Butler Building and above an underground shelter. In EG&G tests comparing real fallout and a pumped source, the two methods disagreed by 15 to 40 percent.

2. Pumped source experiments simulating an infinite field showed ground contribution in the basement of a Butler Building without a first floor slab to be as much as 20 percent less than Engineering Manual calculations in

EG&G tests at the 1-foot level; they were as much as a factor of 2 less for a 6-foot level detector.

3. NRDL found that the $Co^{60}$ pumped source method is satisfactory for simulating real fallout radiation in highly compartmented structures such as ships.

E. Ground Roughness

Ground roughness effects on protection factors are not accounted for in present computational procedures. However, it has been found by NRDL, EG&G, and DRCL that ground roughness can be an important parameter in analyzing protection factors of buildings. Major findings of the review of ground roughness experiments are:

1. The method of correcting for ground roughness in theory to agree with experimental results as if radioactive fallout were buried beneath a layer of earth (or an equivalent layer of air) appears adequate.

2. Both dose angular distribution experimental measurements and dose-height experimental measurements give consistent results for obtaining a theoretical ground roughness correction factor.

3. It is incorrect to use the pumped source simulation method in ground roughness experiments, because the continuous tubing eliminates much of the roughness effect.

F. Computational Procedures

Major findings of the analysis of protection factor computational procedures are:

1. Shortcomings occur in the Engineering Manual treatment of azimuthal sectors, first floor slab exposure, basement dose rates, interior partitions, ceiling shine, and ground roughness.

2. The Equivalent Building Method (Reference 6) offers advantages of speed and simplicity when comparison of alternative structure designs is involved. Results are within ± 10 percent of RTI and OCD calculations using the Engineering Manual. For simple buildings (one or two stories, sill heights above detector level, no partitions, infinite planes of contamination) in the range of 1,000 to 100,000 square feet.

3. The Protection Factor Estimator (Reference 14) is a simplified version of the Equivalent Building Method and agrees within ± 10 percent of the EBM for structures between 1,000 and 10,000 square feet in area. Outside of

these limits, the variation may be as much as 35 percent.

4. The various AE Guides (References 3, 8, and 9) and the NFSS Computer Program (Reference 7) are within $\pm$ 20 percent of Engineering Manual results for simple buildings such as blockhouses, but should not be used for complicated structures.

## IV. RECOMMENDATIONS

The recommendations resulting from the research reported herein are:

1. Wall-scattered radiation, $G_s(\omega)$, is one of the most uncertain parameters in the Engineering Manual procedure. Because of the difficulty of isolating effects experimentally and the lack of theoretical work on this parameter, it is recommended that Monte Carlo calculations be performed to better understand the angular distributions of wall-scattered radiation.

2. The only known studies on sand bag shielding left cracks between the bags which permitted radiation streaming. A more efficient method of stacking the bags possibly could be found. Further experiments and analyses on sand bag shielding are recommended.

3. Additional model experiments of the type reported by DRCL for side wall scattering should be performed with plane sources instead of point sources to determine the resulting dose rates near the sidewalls.

4. Tech Ops' procedures on scaling buildings to determine ground contribution in exposed and unexposed basements do not adequately predict full-scale measurements. Therefore, it is recommended that suitable full-scale exposed and unexposed basement experiments be made to allow an evaluation of the scaling method for model data and to:

    a. Determine the radiation originating from grade level which is scattered into a basement of a partially exposed first floor slab.

    b. Determine the effect of ground roughness on detectors in a basement and in a first story with the first floor slab partially and fully exposed.

    c. Make off-center basement measurements to compare with center measurements. The Engineering Manual predicts a ratio of unity for basement corner to center dose rates, whereas the model experimental ratio is 1.3 for a 24-inch-wide (24-feet full-scale) plane of ground contamination.

5. If the importance of floor-edge scattering observed in models is verified by the recommended full-scale experiment, it is recommended that a calculation procedure be developed for analyzing basements

and first stories in buildings with fractional first floor slab exposure.

6. It is recommended that Engineering Manual calculations be performed for basement off-center detectors subject to limited planes of contamination to allow comparisons of dose rate data with Tech Ops model results.

7. Reference 1 shows how the direct component of ground radiation penetrating a floor slab can actually give rise to an initial increase in dose rate, then a decrease, as the detector is moved downward from the slab. This should be accounted for in the next revision of the Engineering Manual.

8. For structures with numerous interior partitions, it is recommended that the barrier factor be determined by

$$B_w = B_w(X_e)\ B_w(X_p + kX_i)$$

where $B_w$ = barrier factor for the exterior wall, $X_e$ = psf of exterior wall, $X_p$ = psf of parallel partitions, $X_i$ = psf of cross partitions, and $k = \frac{1}{2}$. If a single barrier of the total mass thickness is used in an analysis for compartmented structures, it should be regarded as a conservative method of calculation.

9. It is recommended that the ceiling shine procedure proposed by Tech Ops be included in the revision of the Engineering Manual as an ancillary method for handling upper stories of tall buildings.

10. Since all of the more accurate methods for computing PF's (including the various computer programs) use the azimuthal sector method, it is recommended that a more accurate procedure be incorporated into the present Engineering Manual procedure to account for the variation in contribution of azimuthal sectors of identical size centered on different azimuthal angles. Subsequent incorporation into computer programs is advisable.

11. For rough terrain, such as plowed fields, macroscopic ground roughness would affect real fallout fields to a greater degree than it would the pumped source. Although results in the experiments comparing the pumped source method with real fallout were quite similar, ground roughness was not severe. Therefore, effects of macroscopic ground roughness should be measured experimentally, and calculated using Monte Carlo procedures.

12. Until recommendation 10 or its equivalent is implemented, a factor of 2 should be used in calculational procedures to decrease the dose rate above moderately rough terrain (plowed ground) to account for ground roughness.

13. Additional ground roughness experiments should be performed on surfaces most frequently occurring around fallout shelters. It is recommended that laboratory model tests be performed on geometrically simple ground roughness patterns like parallel furrows or circular patterns using scaled contamination and roughness. If these results indicate significant reductions in dose rates due to ground roughness, full-scale measurements should be made to determine ground roughness factors for surfaces expected around fallout shelters. Examples of such surfaces are grass, sidewalks, tar and gravel roofs, and city streets.

14. Better instrumentation should be used on all future ground roughness tests, since one of the major problems in past experiments was caused by instrument errors and the influence of heat, dust, and low radiation intensity on instrument stability.

## REFERENCES


1. E. L. Hill, W. K. Grogan, R. O. Lyday and H. G. Norment. Analysis of Survey Data. Final Report R-OU-81 (Parts I and II). Durham, North Carolina: Research Triangle Institute, 15 February 1964.

2. L. V. Spencer. Structure Shielding Against Fallout Radiation from Nuclear Weapons. National Bureau of Standards Monograph 42. Washington: U. S. Department of Commerce, 1 June 1962.

3. Office of Civil Defense. Fallout Shelter Surveys: Guide for Architects and Engineers. Washington: Office of Civil Defense, Department of Defense, December 1961.

4. Office of Civil Defense. Design and Review of Structures for Protection from Fallout Gamma Radiation. (Engineering Manual). PM 100-1. Interim Edition. Washington: Office of Civil Defense, Department of Defense, February 1965.

5. Office of Civil Defense. Shelter Design and Analysis, Volume 1, Fallout Protection. Washington: Office of Civil Defense, Department of Defense, September 1962.

6. J. C. LeDoux. Equivalent Building Method. Shelter Design and Analysis. Volume 2. Washington: Office of Civil Defense, Department of Defense, February 1963.

7. L. V. Spencer and C. Eisenhauer. Description of Computer Program for the National Fallout Shelter Survey. National Bureau of Standards Report No. 7826. Washington: U. S. Department of Commerce, 15 March 1963.

8. Privy Council Office. An Engineer Looks at Fallout Shelter. A Manual for Architects and Engineers. Emergency Measures Organization Manual No. 1. Ottawa, Canada: Privy Council, 1961.

9. Home Office. Assessment of the Protection Afforded by Buildings Against Gamma Radiation Fallout. London, England: Home Office, 1957.

10. R. R. Putz and E. Kuykendall. A Comparison of Computed and Experimentally Observed Intensity Levels for Various Gamma Radiation Source Distributions and Shielding Conditions in Residential Structures. Civil Defense Research Project, Series No. 2, Issue No. 16, Berkeley, California: University of California, Institute of Engineering Research, 2 February 1959.

11. C. Eisenhauer. An Engineering Method of Calculating Protection Afforded by Structures Against Fallout Radiation. PM-100-1, Supplement No. 1, NBS Monograph 76. Washington: Department of Defense. Office of Civil Defense, January 1964.

12. Office of Civil Defense. Electronic Analysis of Structures for Fallout Gamma Radiation Shielding. PG 80-16 (Final Draft). Washington: Office of Civil Defense, Department of the Army, June 1965.

13. E. L. Hill, T. Johnson, and R. O. Lyday, Jr. Computer Program for Analysis of Building Protection Factors. RM-205-1 (Parts I and II). Durham, North Carolina: Research Triangle Institute, 6 July 1965.

14. J. C. LeDoux. Protection Factor Estimator. TM-64-1. Washington: Office of Civil Defense, Department of Defense, May 1964.